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Hardened Subminiature Telemetry and Sensor Systems (HSTSS) Subsystems Flight Test Results

Eugene M. Ferguson
Lawrence W. Burke, Jr.
Michael S. L. Hollis
Craig R. Myers
Eric S. Irwin
Charles E. Mitchell

ARL-TN-59 February 1996

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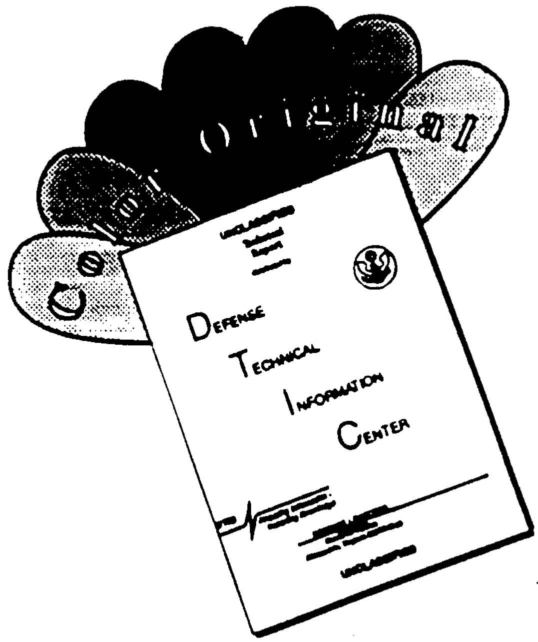

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	February 1996	Final, Jun 94 - Mar 95

4. TITLE AND SUBTITLE
Hardened Subminiature Telemetry and Sensor Systems (HSTSS) Subsystems Flight Test Results

5. FUNDING NUMBERS
PR: 1L162618AH80

6. AUTHOR(S)
Eugene M. Ferguson, Lawrence W. Burke, Jr., Michael S. L. Hollis, Craig R. Myers, Eric S. Irwin, and Charles E. Mitchell

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Research Laboratory
ATTN: AMSRL-WT-WB
Aberdeen Proving Ground, MD 21005-5066

8. PERFORMING ORGANIZATION REPORT NUMBER
ARL-TN-59

9. SPONSORING/MONITORING AGENCY NAMES(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Under the Hardened Subminiature Telemetry and Sensor Systems (HSTSS) Program, two 120-mm M831 projectiles were modified to test the survivability of a multichip module (MCM) and a solid-polymer electrolyte-battery technology. Tests were conducted at the U.S. Army Research Laboratory's (ARL) Transonic Range facility on 6 December 1994 and 8 December 1994. The projectiles experienced launch accelerations of 21,000 g's and 14,000 g's, respectively. Modifications included replacing the M831 spike-nose assembly with a custom-built assembly, which housed an MCM, two solid-polymer batteries arranged with different orientations, and a three-channel FM/FM telemetry system. Malfunctions with the telemetry link on the first firing yielded inconclusive results about the MCM survival of the gun launch; however, this problem did not completely annihilate the evidence which suggested that the solid-polymer batteries survived. Results from the second firing showed that both the MCM and the solid-polymer batteries survived the gun launch.

14. SUBJECT TERMS
telemetry, polymer battery, multichip module (MCM), acceleration, instrumentation

15. NUMBER OF PAGES
27

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

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ACKNOWLEDGMENTS

The authors would like to express their appreciation to Mr. David J. Hepner, Ms. Elisa A. Jara, and Mr. Louis M. Gobern of the Weapons Technology Directorate (WTD), U.S. Army Research Laboratory (ARL), for their assistance with data reduction. The authors are also indebted to the Transonic Range facility personnel for their technical assistance with the test firing.

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1. INTRODUCTION

The Weapons Technology Directorate (WTD) of the U.S. Army Research Laboratory (ARL) at Aberdeen Proving Ground (APG) and the U.S. Army Test and Evaluation Command (TECOM) at Yuma Proving Ground (YPG) are currently conducting a program entitled "Hardened Subminiature Telemetry and Sensor Systems" (HSTSS). This program has been part of the Test Technology Development and Demonstration (TTD&D) Project sponsored by the Director of Test Facilities and Resources, Office of the Secretary of Defense (OSD). HSTSS has been established to develop and demonstrate a new generation of rugged subminiature instrumentation measurement technologies. These new sensor and telemetry components are being designed to withstand shock levels in excess of 100,000 g's and spin rates over 300 rps. The overall goal of this program is to make these devices readily available and affordable to the Army and DOD, in general, for testing smart weapon systems.

2. BACKGROUND

Munition testing is typically performed using external optical and radar-tracking equipment. Although these data are valuable, they do not provide the tester with internal health information, such as the condition of guidance and control systems. Data such as spin, pitch, and yaw rates and pitch and yaw angle for the entire flight are also not realized by only making external measurements. All of these parameters are important when testing and developing smart weapon systems. These measurements combined with external measurement data would provide a complete data package.

The HSTSS program has been chartered to develop and qualify telemetry subsystems and components which will be low cost, small in volume, and able to survive harsh launch environments. This program is developing telemetry transmitters, antennas, conformal power supplies, programmable high-density multichip modules (MCM), physical sensors, and programmable data acquisition chip sets. This modular/component design approach will allow the designer to configure a measurement system to fit practically any form factor. This report discusses the flight test results of a high-g MCM package and of a solid-polymer battery. Both of these technologies have been under evaluation for the HSTSS program.

3. PRELIMINARY TESTING

Both the battery technology and MCM technology had been pretested prior to these flight tests. The solid-polymer batteries have survived shock table tests, spin tests, and air gun tests throughout their development. These batteries have been shown to survive shock levels in excess of 80,000 g's. More detailed data can be found in Burke, Faust, and Mitchell (1994) and Burke, Faulstich, and Newnham (1995).

The MCM package has also been tested using both a shock table and air gun and has routinely survived accelerations in excess of 20,000 g's. More detailed information on these tests can be found in Alper (1993) and Burke et al. (1994).

The signal conditioning and mixing board of the telemetry system was also pretested using the ARL shock table facility. This four-layer printed wiring board consisted mainly of through-hole and surface-mounted electronic components and three Inter-Range Instrumentation Group (IRIG) standard subcarrier oscillators (SCOs). This board also provided connection to the MCM package. The board is shown in Figure 1 with the MCM attached. A spare board with duplicate components, minus the MCM package, was shocked multiple times to levels exceeding 29,000 g's without experiencing any failures. Figure 2 shows the test fixture mounted to the shock table. A typical acceleration profile generated from this shock table is shown in Figure 3.

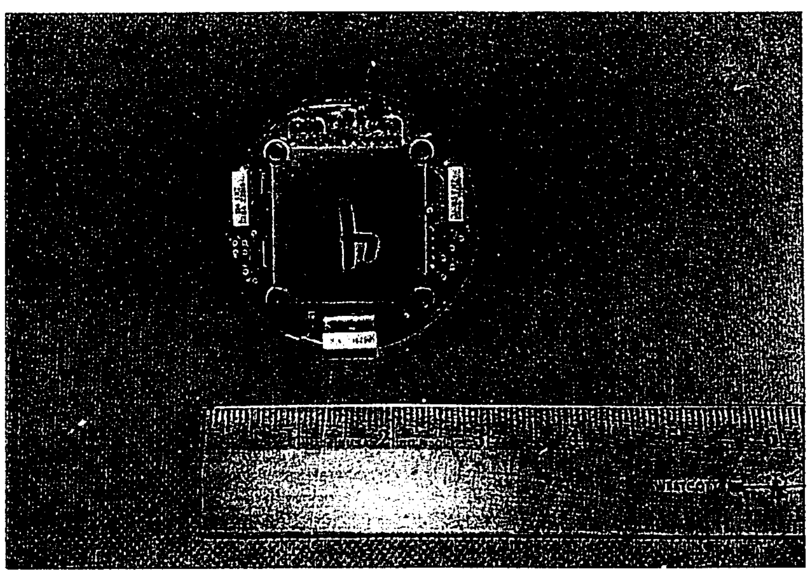

Figure 1. MCM mounted to signal conditioning and mixing board.

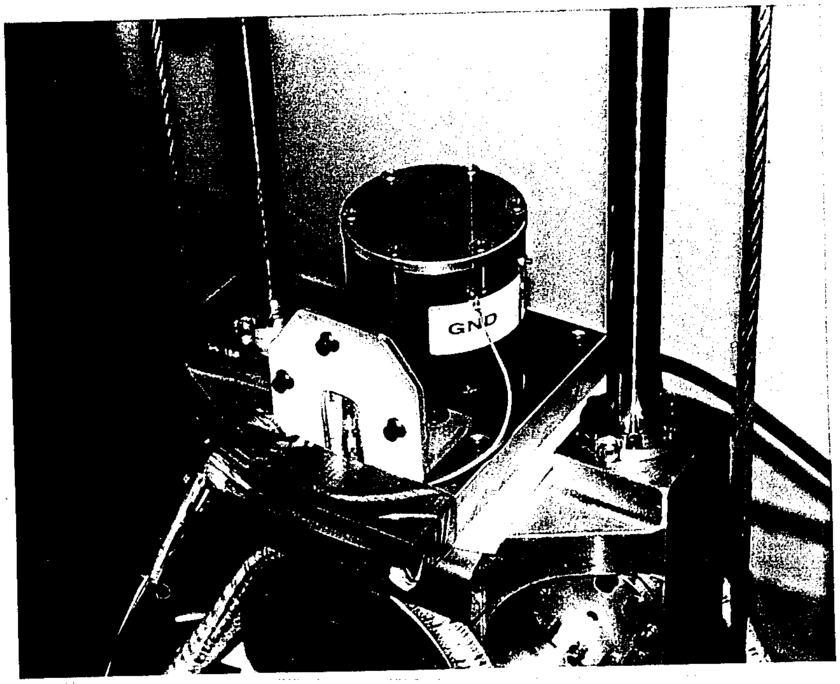

Figure 2. Encapsulated MCM on shock table.

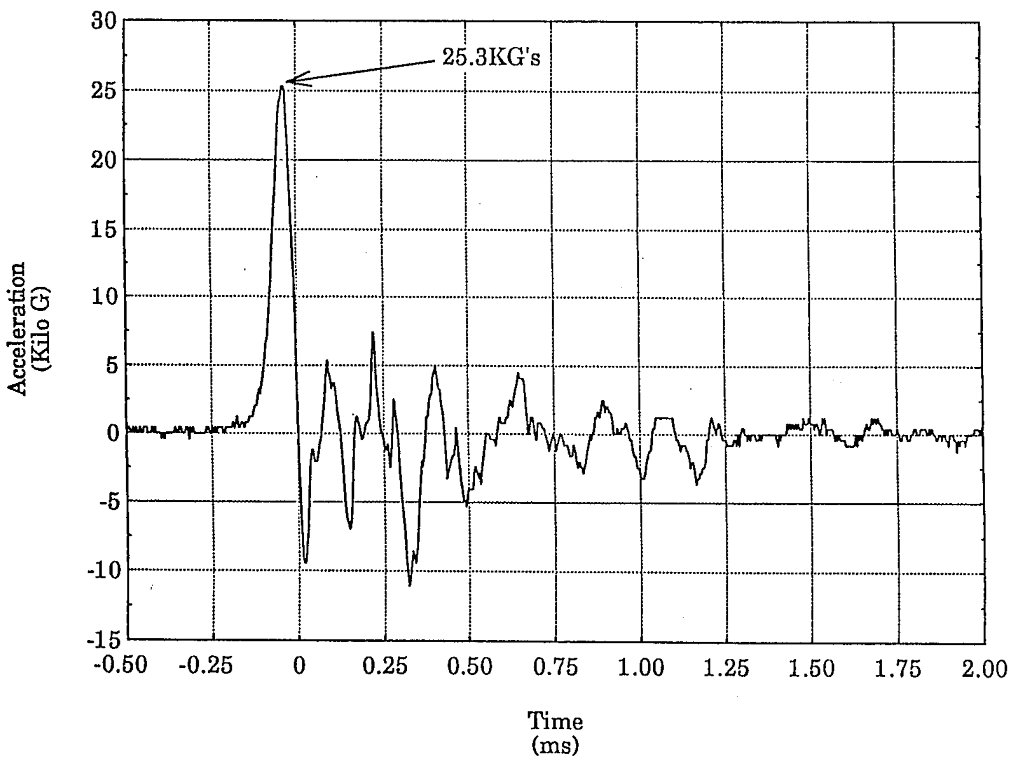

Figure 3. Typical acceleration profile from shock table.

4. FLIGHT TESTS

In order to gun qualify the MCM package and the solid-polymer electrolyte battery, a test vehicle was designed to hold these items and attach them to an existing projectile. The test vehicle chosen was a modified 120-mm, M831, TP-T tank round. The major modification was to replace the screw in spike-nose with a nose section that could hold the MCM package, two polymer batteries, and a three-channel FM/FM telemetry system to monitor component performance. Two of these test vehicles were assembled. Figures 4 and 5 show the layout of the electronics and an assembled unit. Two polymer batteries were used so that the performance at both vertical and horizontal orientations (with respect to the projectile spin axis) could be studied.

The MCM package contained a yawsonde sun-sensor amplifier/mixer circuit and a delay circuit implemented with analog-to-digital and digital-to-analog converters. When functioning properly, the MCM package produces a bidirectional pulse train typical of ARL yawsonde systems (Ferguson, Hepner, and Clay 1993). The polymer-electrolyte batteries were charged to a nominal 3-V level. Once turned on, the batteries were subjected to a 1-KΩ load. Each of the test items was assigned to one of the three channels of the L-band, FM/FM telemetry system, which allowed for continuous monitoring through a radio link. The MCM used the 70-kHz SCO channel, the horizontal battery used the 93-kHz SCO channel, and the vertical battery used the 124-kHz SCO channel.

A ground station for receiving the telemetered data was set up as shown in Figure 6. The ground station consisted of two circularly polarized L-band antennas, two L-band preamplifiers providing a gain of 35 dB, two 100-ft lengths of 1.2 noise figure RF cable, two receivers, and a 14-track analog tape recorder.

5. RESULTS

The vehicles were launched from a smoothbore, 120-mm, M256 cannon at the ARL Transonic Range Facility. The gun was positioned to an azimuth of 202° from true north and a quadrant elevation (QE) of 30°. The first test vehicle, designated HST03, was launched on 6 December 1994 using a charge weight of 4.47 kg to provide an estimated peak acceleration of 21,000 g's.

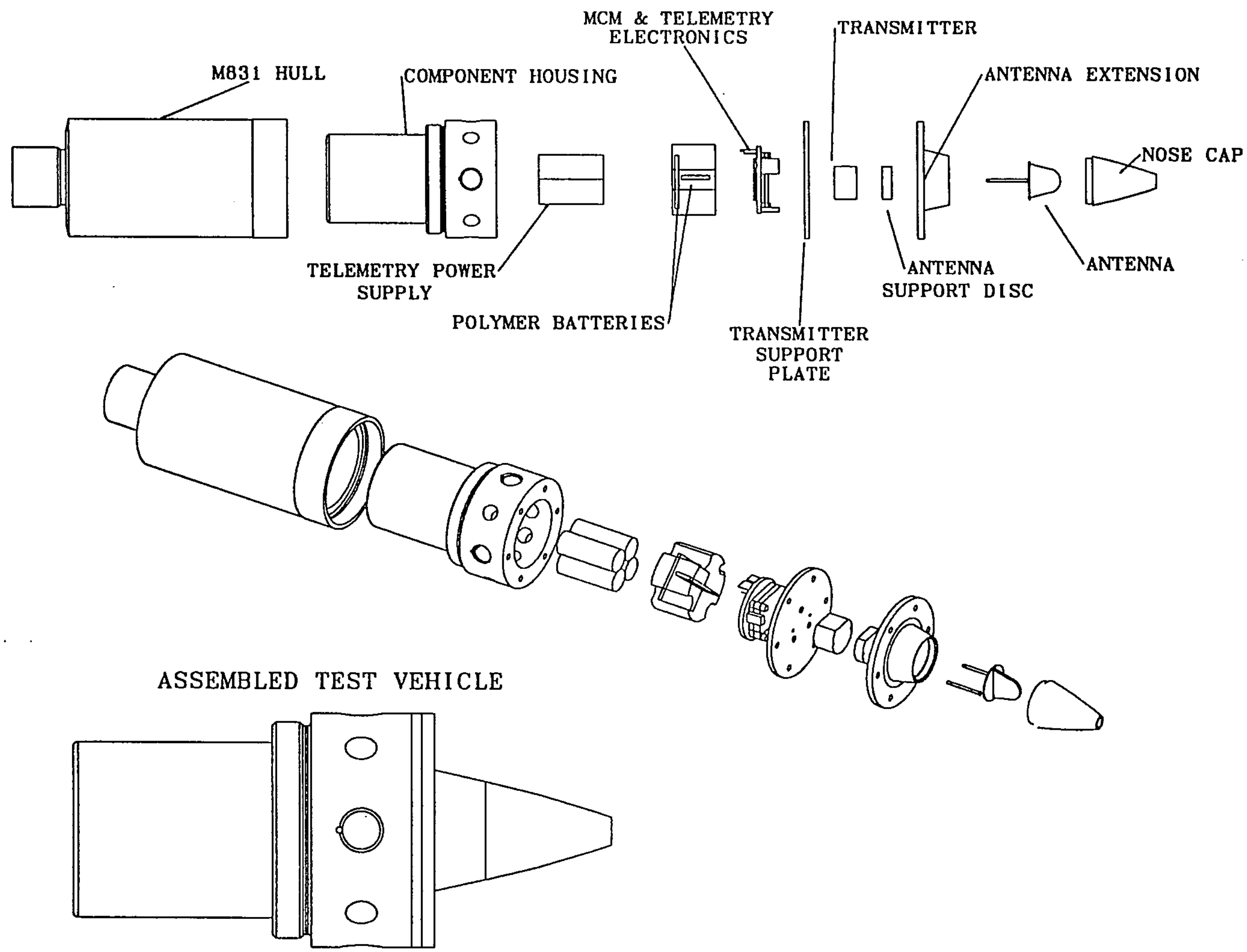

Figure 4. Layout of components in test vehicle.

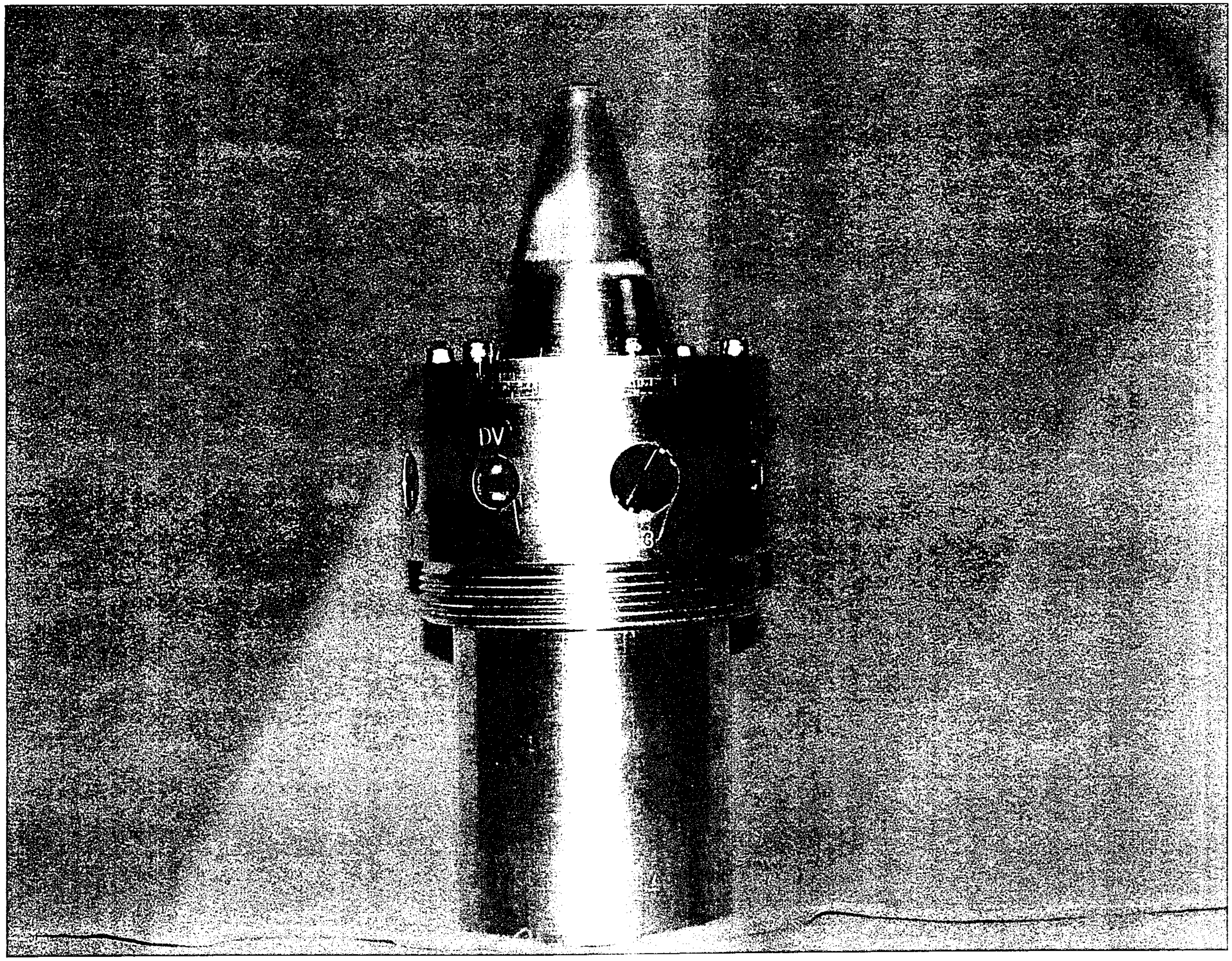

Figure 5. Assembled test vehicle.

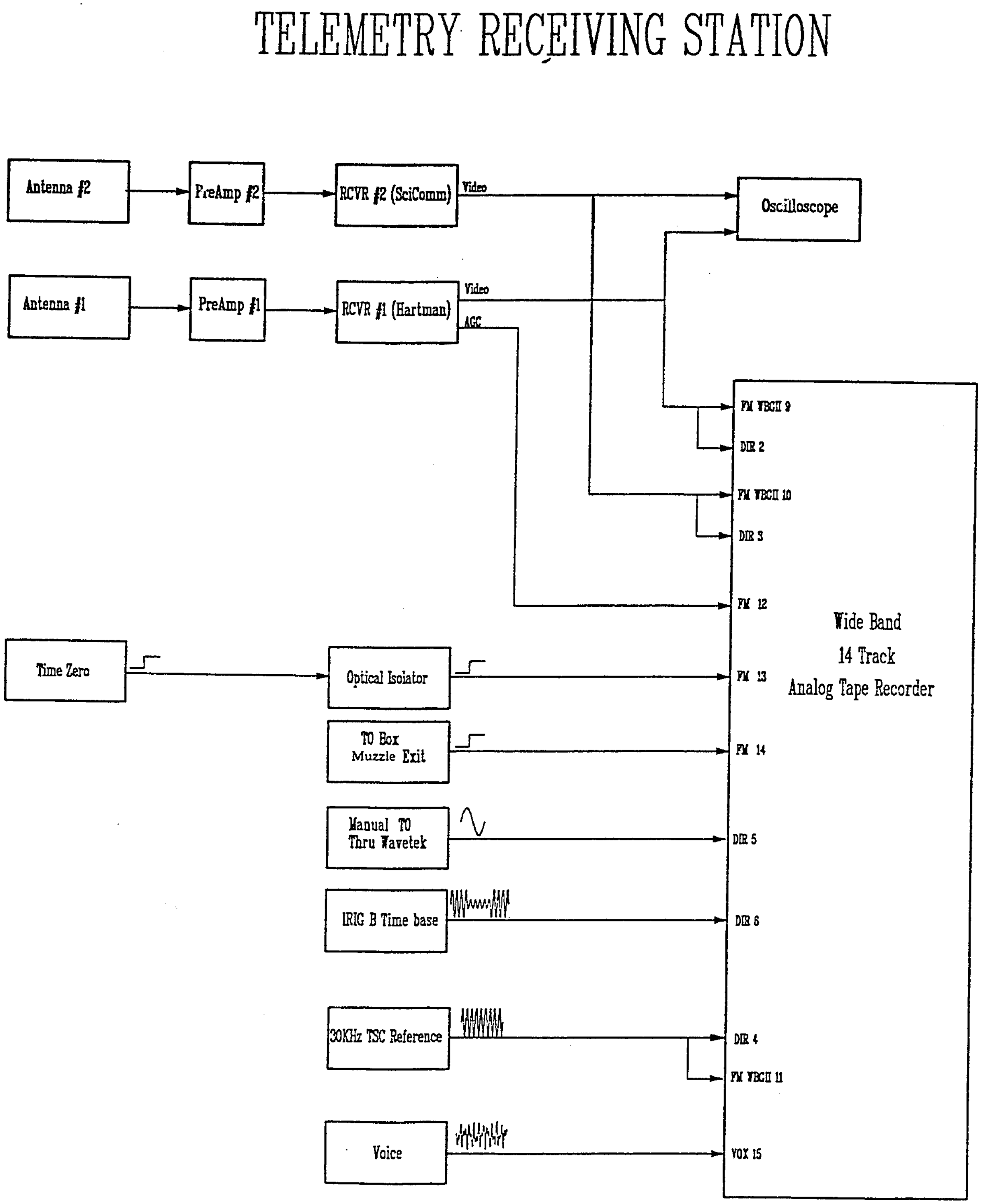

Figure 6. Telemetry receiving station setup.

When acquiring the telemetered data from the test vehicle, the automatic gain control (AGC) signal of one receiver was also monitored. This AGC signal is proportional to the strength of the received signal, and if calibrated, it can be used to measure received signal strength. The AGC signal generated by HST03 is shown in Figure 7 (please note that time = 0 corresponds to projectile muzzle exit in this and all plots in this report). This plot shows that the telemetered signal was being received at about a –60 dBm strength 15 ms prior to muzzle exit. The signal is then greatly attenuated at about 5 ms prior to muzzle exit. This attenuation is typical and is probably due to the formation of ionized gases between the transmitting and receiving antennas in the telemetry link. At muzzle exit, a pulse is generated on the AGC signal. The mechanism which causes this pulse is not yet understood, but it does seem to be an artifact of smoothbore projectile launches that use L-band telemetry systems. After the pulse at muzzle exit, the AGC signal usually rises to its maximum and slowly decreases at a rate inversely proportional to the square of the projectile distance from the receiving antenna; but for HST03, the received signal remained very low until about 18 ms after muzzle exit and only remained strong for about 1.5 ms. This situation is unusual and seems to point to a failure in the telemetry link.

Figures 8, 9, and 10 show the in-bore voltage levels for the three test items. The MCM was at a 2.77-V level, the vertical battery was at 2.4 V, and the horizontal battery was at 1.6 V before the telemetry link was interrupted. The data loss 5 ms prior to muzzle exit is expected based on the examination of the AGC signal.

Fortunately, the 1.5 ms of strong signal was sufficient to conduct at least some analysis. The analog tape was played back at 1/16th speed to examine the receiver video signal at this portion of the flight. Figures 11a, 11b, and 11c show the video signal at the region in question scaled to real time. This data appeared to be periodic and valid for 1.6 ms starting at 18.6 ms after muzzle exit. The periodic portion of the video was then played back at 1/160th speed into a spectrum analyzer. A waterfall plot of the frequency-shifted video signal is shown in Figure 12. The three dominating frequencies in the plot (406 Hz, 574 Hz, and 775 Hz) are 1/160th of realistic values for the three SCOs used for the three channels in the telemetry system. These frequencies were read, scaled to their real-time values, and applied to prelaunch channel calibrations.

Figure 13 shows the results of this processing. The MCM output was 0.1 V, the vertical battery output was 2.5 V, and the horizontal battery output was just under 2.0 V. The output voltage from the MCM was too low and indicates a failure with this component. The MCM failure may have been induced

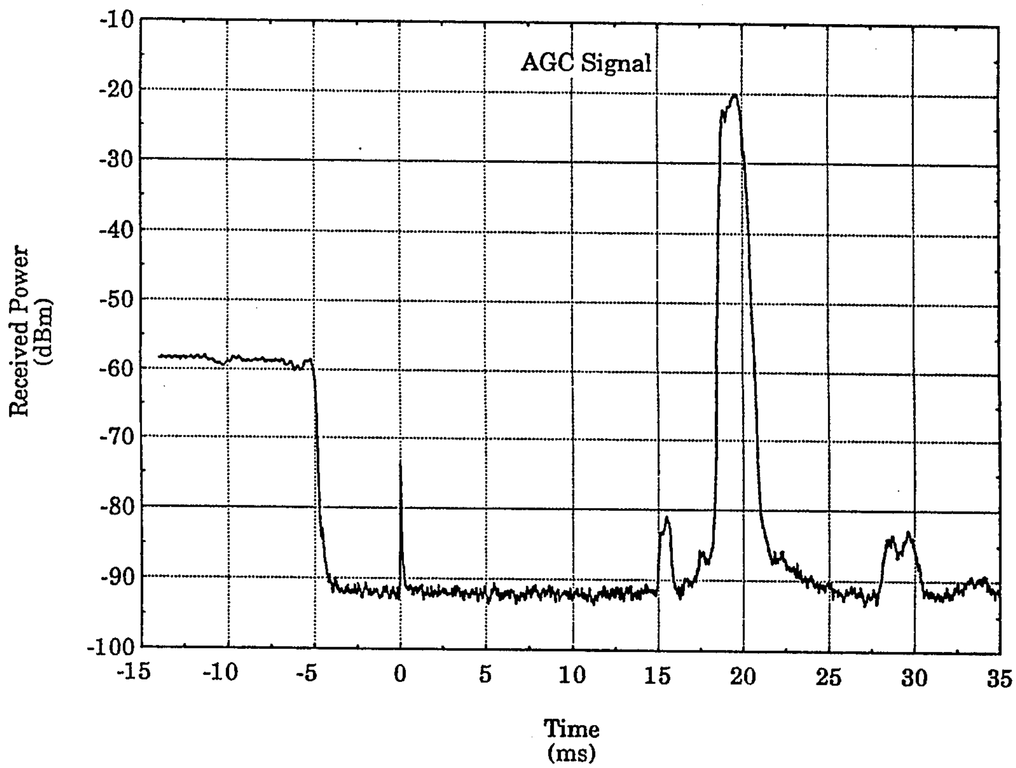

Figure 7. AGC signal generated by HST03.

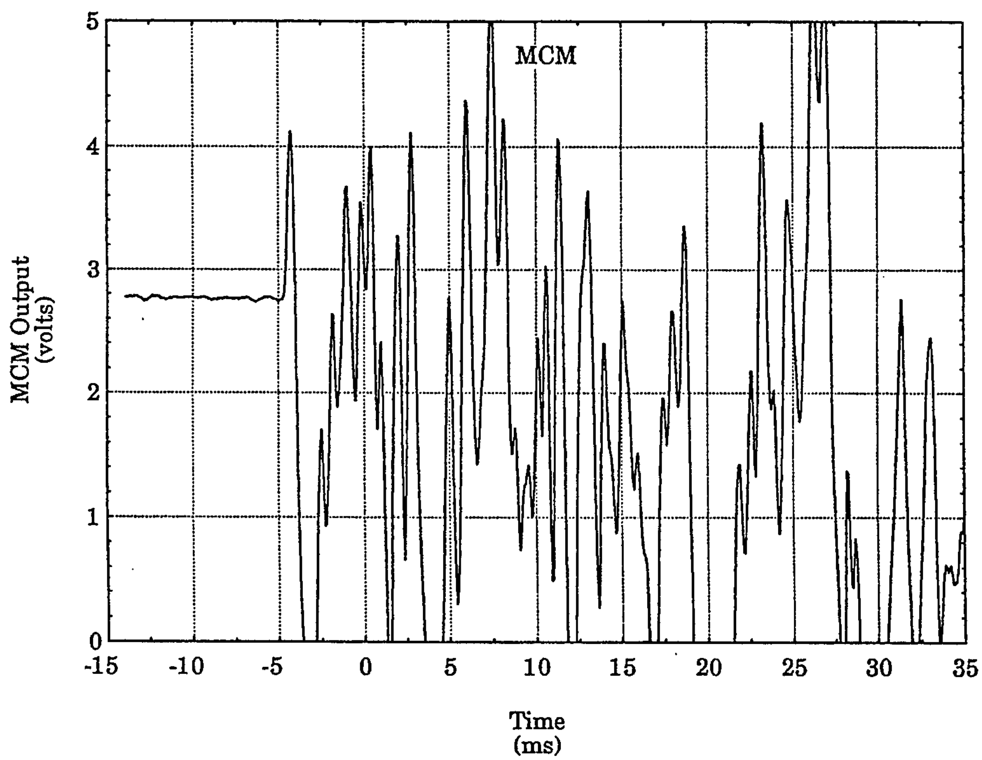

Figure 8. MCM output from HST03.

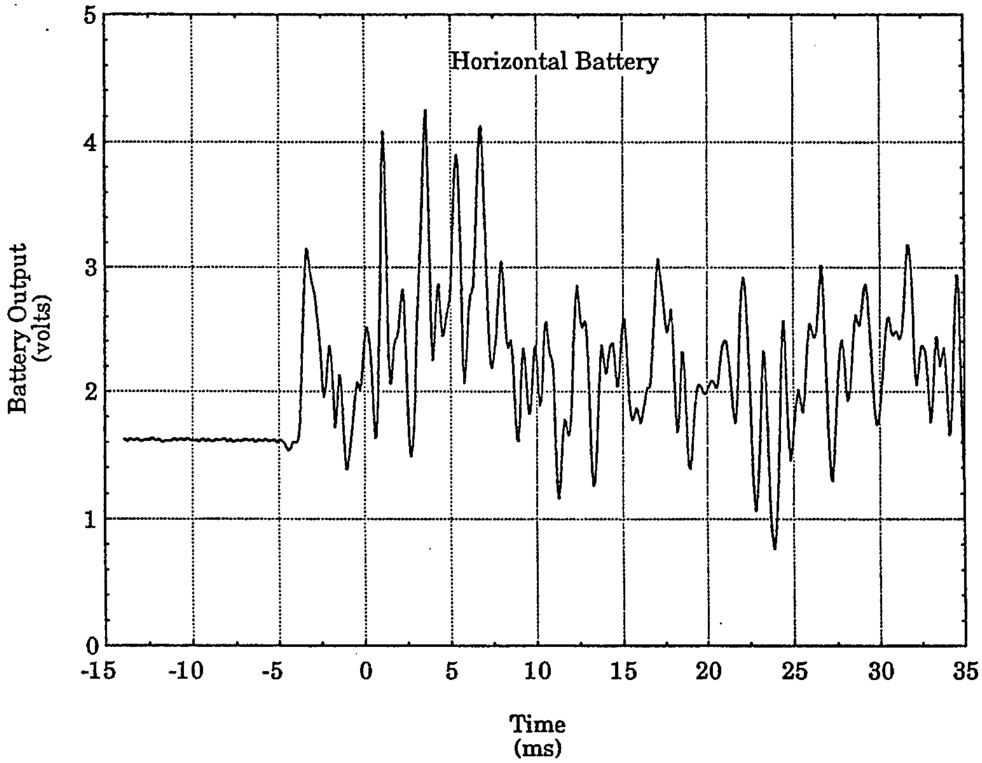

Figure 9. Horizontal battery output from HST03.

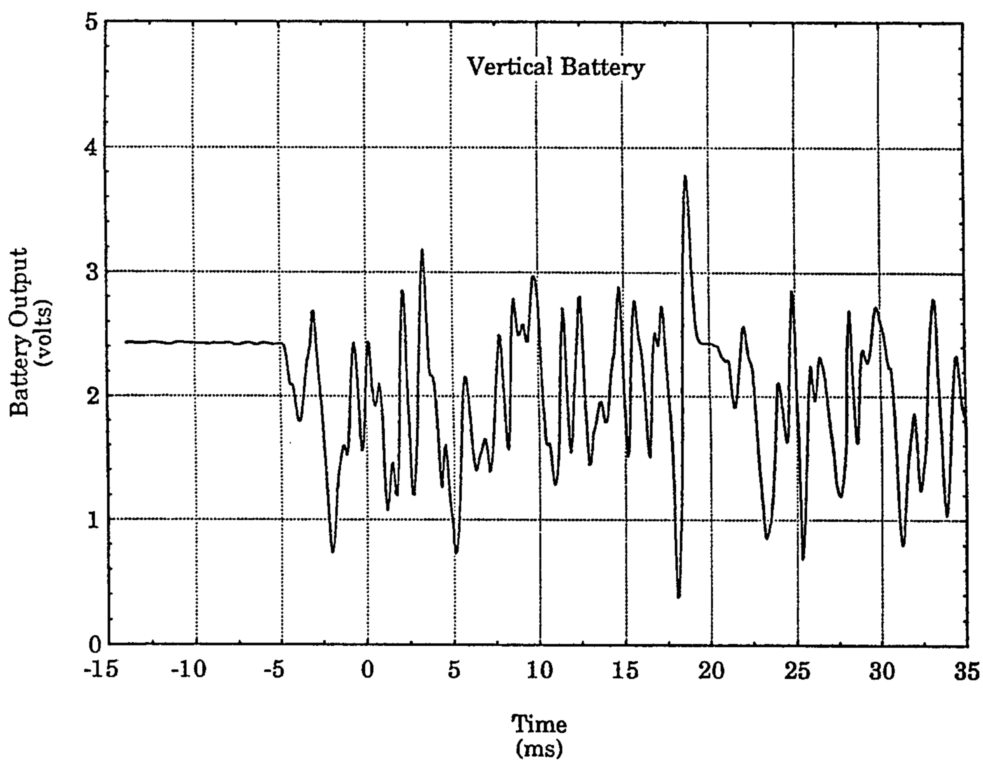

Figure 10. Vertical battery output from HST03.

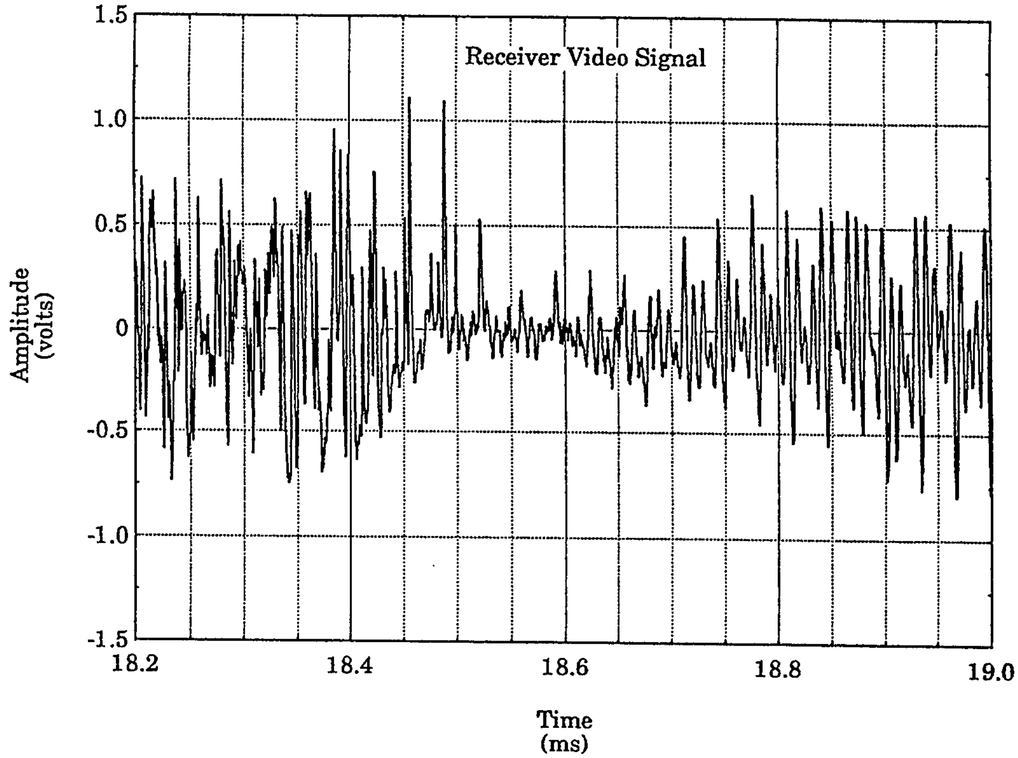

Figure 11a. Receiver video signal from HST03.

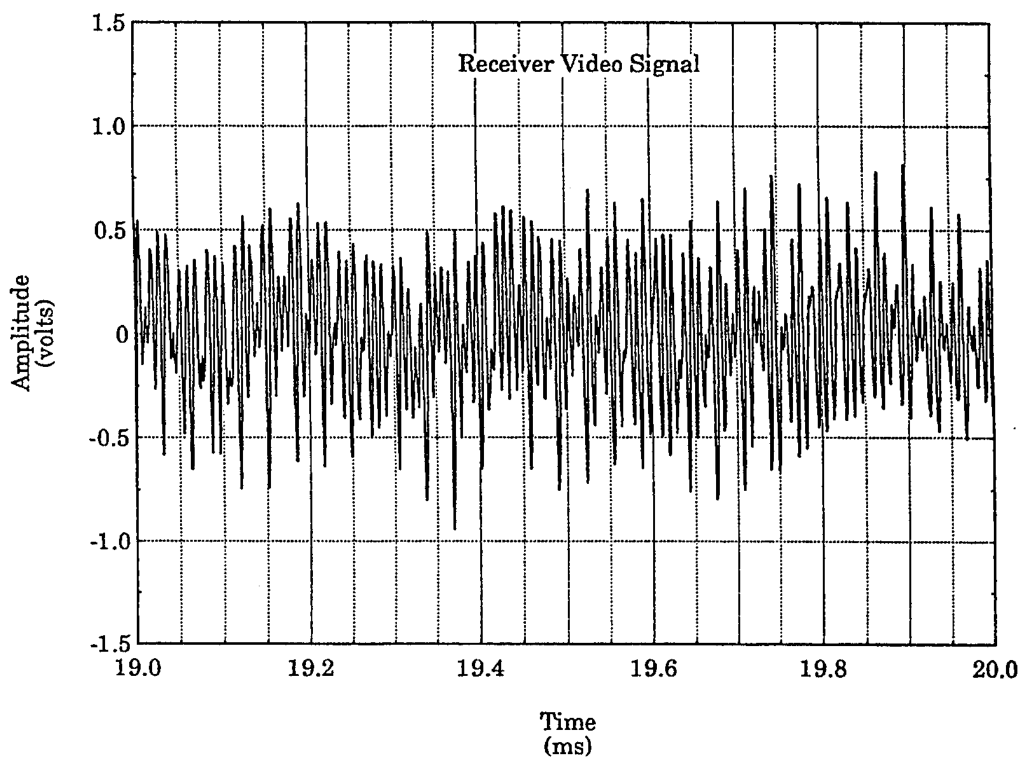

Figure 11b. Receiver video signal from HST03.

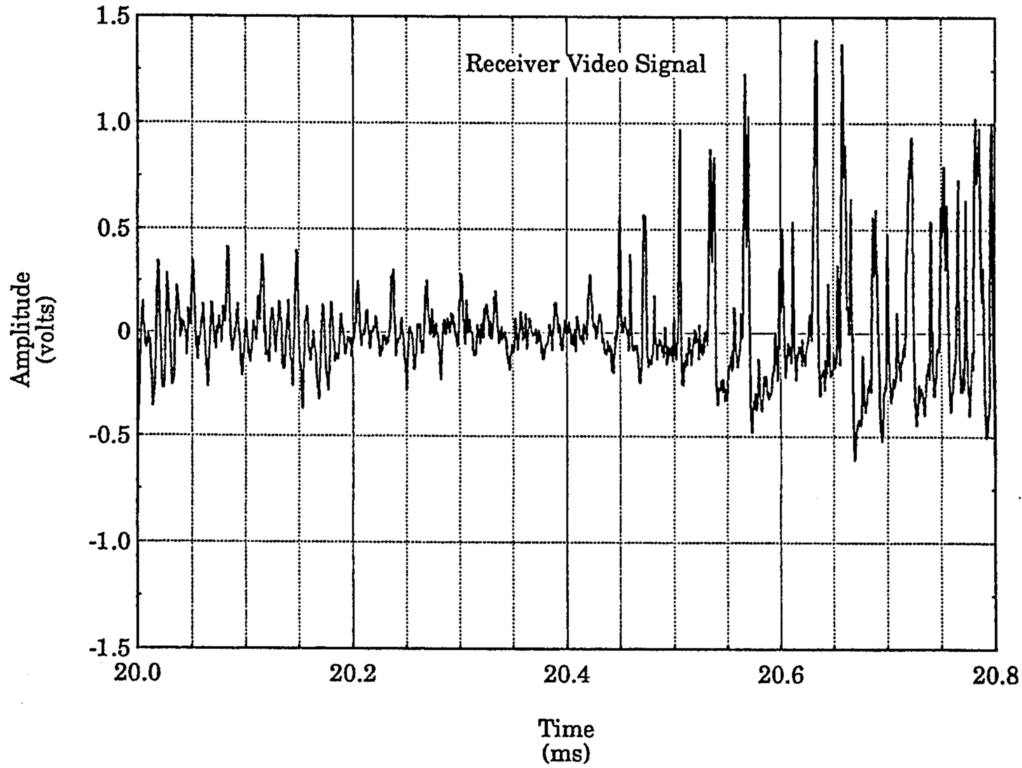

Figure 11c. Receiver video signal from HST03.

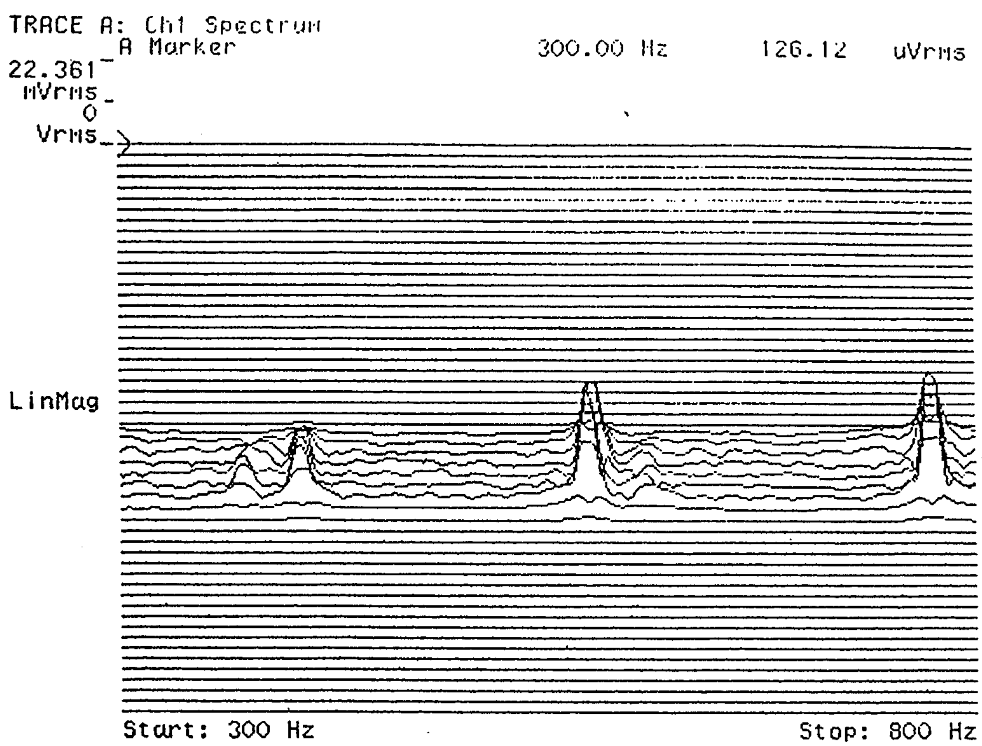

Figure 12. Waterfall plot of receiver video from HST03.

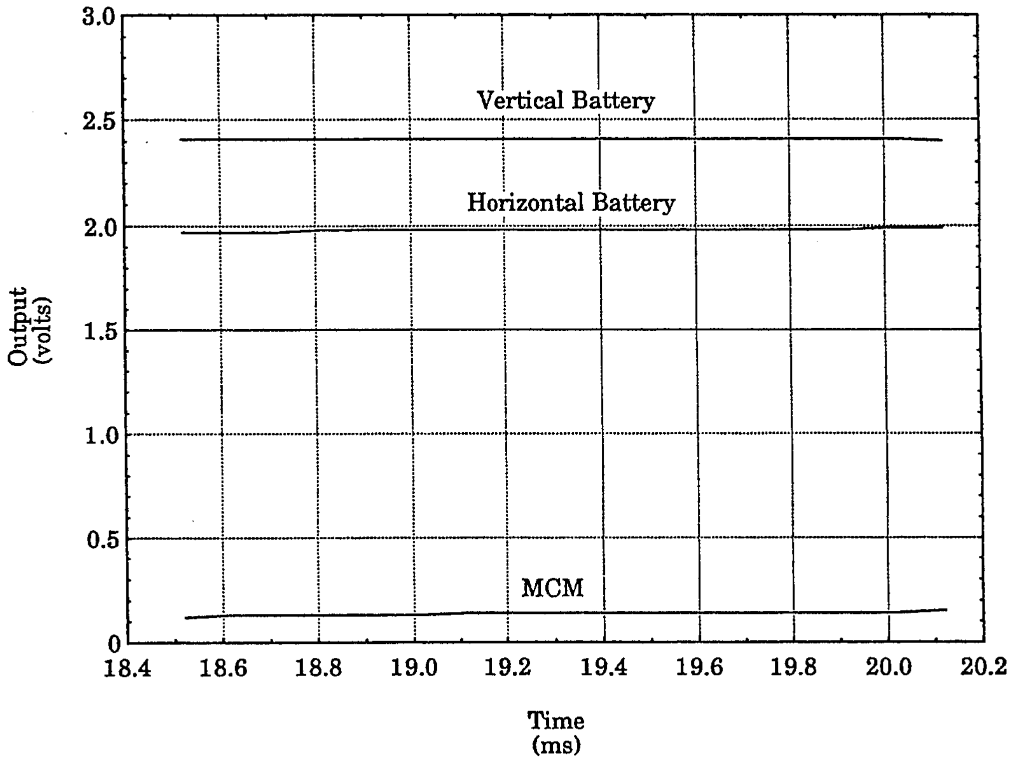

Figure 13. Output of MCM and batteries from HST03.

by the problems with the telemetry system. It can be clearly seen, however, that both vertical and horizontal batteries survived the launch. The horizontal battery even gained about 400 mV, which is a documented characteristic of polymer-electrolyte batteries when they are shocked in this orientation (Burke, Faust, and Mitchell 1994).

The second test vehicle, HST04, was launched on 8 December 1994, under all of the same firing conditions as HST03 except the charge weight. HST04 had 3.57 kg of propellant which accelerated it to a peak of about 14,000 g's. The charge on this round was reduced to increase its probability of survival in light of the problems experienced with HST03.

A portion of the AGC signal for HST04 is shown in Figure 14. The telemetered signal was received at about a −50 dBm strength until about 11 ms prior to muzzle exit. The signal was then greatly attenuated until muzzle exit when the characteristic pulse was generated. Soon after the muzzle exit pulse, the signal strength quickly rose and began to decrease inverse proportionally with projectile distance downrange. AGC signals with this profile are indicative of a properly functioning telemetry link.

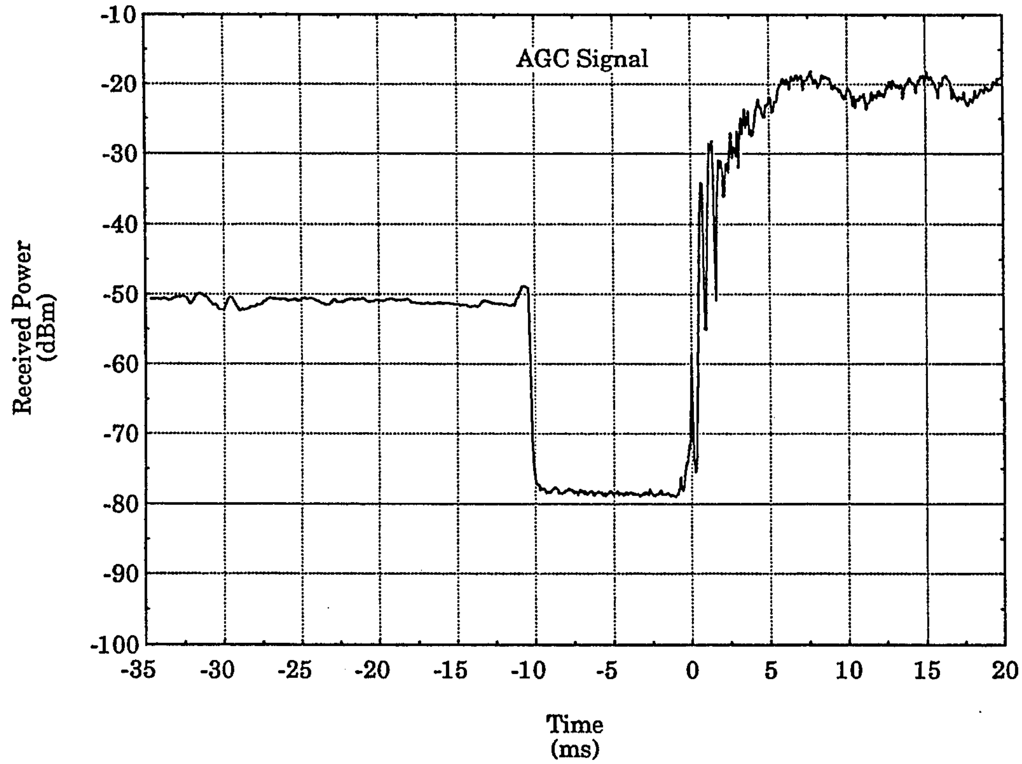

Figure 14. AGC signal generated by HST04.

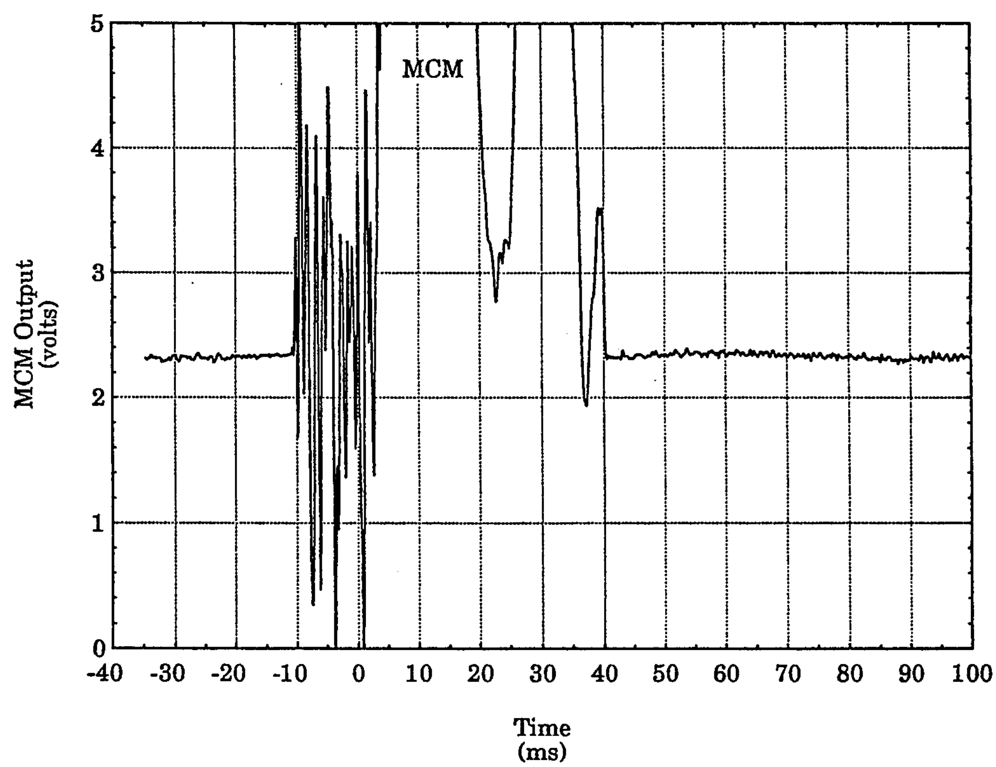

Figure 15. MCM output from HST04.

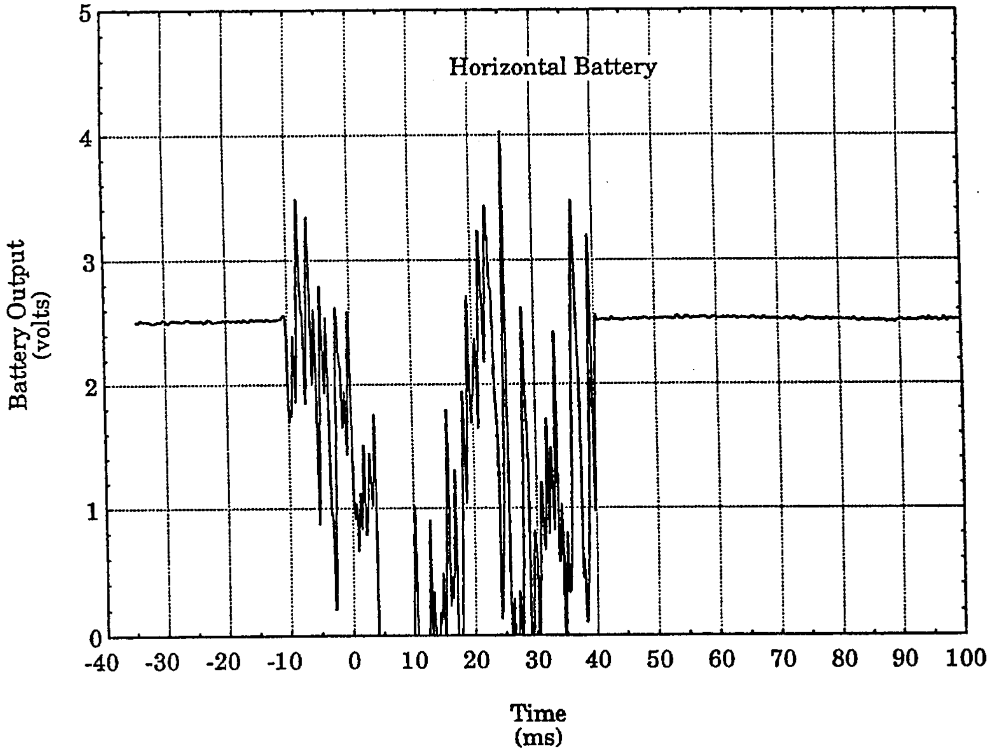

Figure 16. Horizontal battery output from HST04.

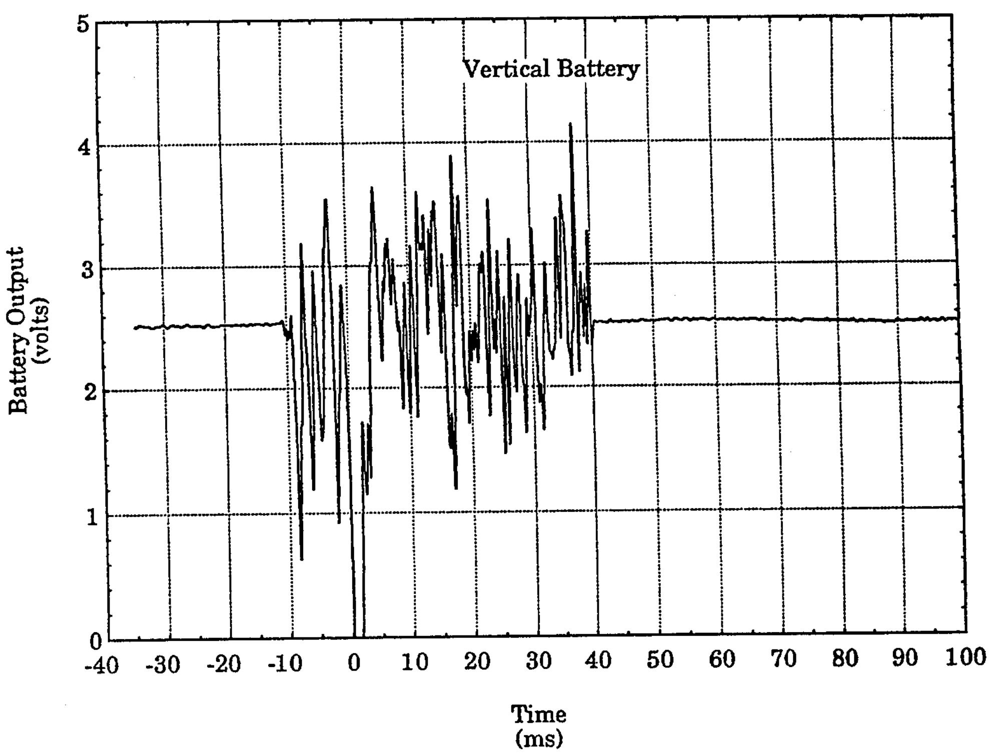

Figure 17. Vertical battery output from HST04.

In-bore and free-flight voltage levels of the three test items are shown in Figures 15, 16, and 17. The MCM's output voltage prior to muzzle exit was at an acceptable level of about 2.3 V. During free flight, bidirectional yawsonde pulses were generated by the MCM (see Figure 18). These pulses and the correct bias voltage indicate that all of the circuitry within the MCM package was functioning properly. The vertical and horizontal batteries seemed to have survived as well. They both had an in-bore voltage of about 2.5 V and a free-flight voltage of essentially 2.5 V. The noise between 10 ms and 40 ms was due to combination of the break in the telemetry link and settling times for the discriminators used to reduce this data. The yawsonde pulse data produced by the MCM were processed to yield the spin rate (solar roll rate) and yaw angle (sigma-n) histories of the test projectile. These data are plotted in Figures 19 and 20.

6. SUMMARY

Test data from HST03 (21,000 g's) showed that the polymer batteries performed well during the interior ballistic regime of launch. (It should be noted that the maximum G-loading is achieved while the projectile is within the bore of the gun.) Very limited telemetry data were available for the free-flight regime; however, there was data that indicated that the polymer batteries survived the launch.

Test data from the MCM on HST03 also indicated that there may have been a failure in either the MCM or its particular telemetry channel. It is not known to the authors what caused the break in the telemetry link; however, the following describe the most probable failure modes based on the observed data:

- a break in the transmitting antenna feed,
- a severely shifting transmitter center frequency, or
- an overly discharged power supply.

Delays during the firing sequence of this round lends credence to the overly discharged power supply scenario.

Test data from HST04 (14,000 g's) showed that both the solid-polymer electrolyte batteries and the MCM performed well throughout the entire flight.

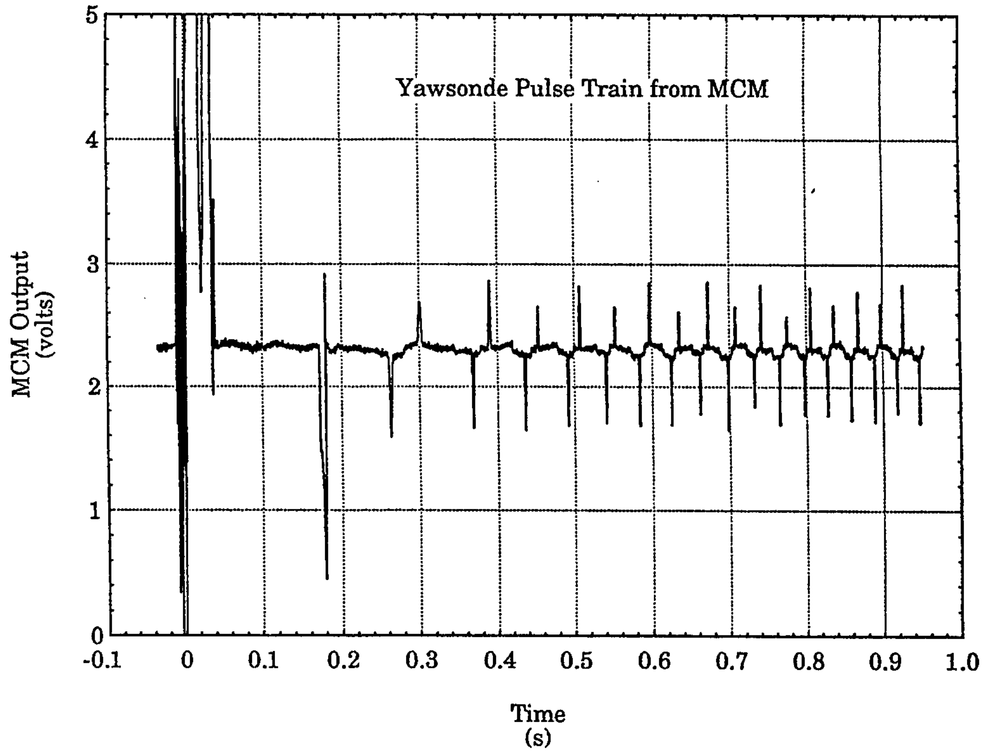

Figure 18. Yawsonde pulse train from MCM on HST04.

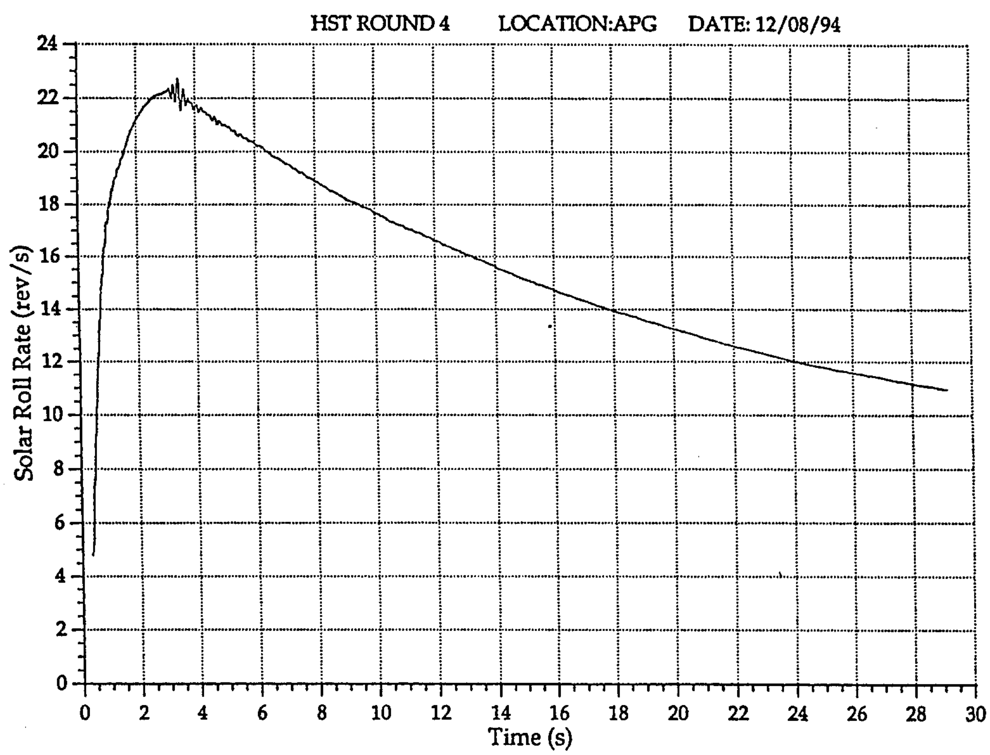

Figure 19. Spin history of HST04.

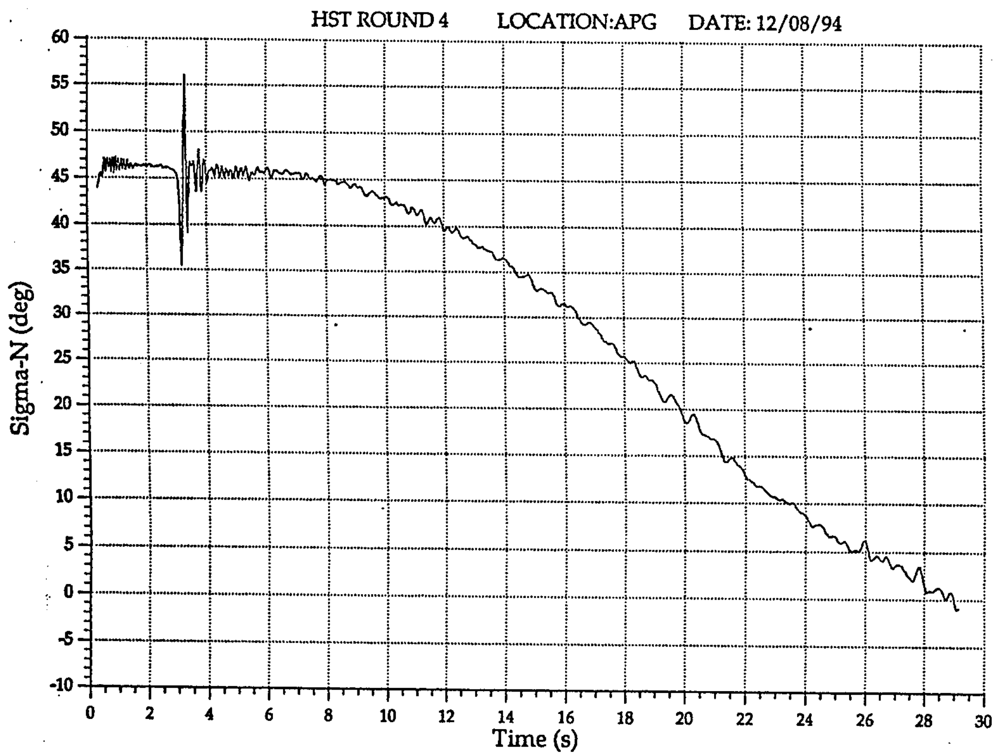

Figure 20. Yaw history of HST04.

Further evaluation and development of both polymer batteries and programmable MCMs, as well as other technologies, will continue under the HSTSS program. This program is currently scheduled for Army funding through FY01 and is also scheduled for Central Test Evaluation Investment Program (CTEIP), OSD funding starting in FY98.

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